Coulomb Sum Rule Experiment

Precision Measurement of R_L and R_T of Quasi-Elastic Electron Scattering

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and

Hall-A Collaboration

Outline

- Motivation
- Previous Results
- New Experiment at JLab
- A few preliminary results
- Summary

Electron Scattering on Nucleons

- Excellent tool to study properties of nucleons, nuclei etc.
  - Charge distribution of various nucleus
  - Elastic form factors of nucleons
- Goal: Study of the nucleon properties inside the nucleus
- How? - Comparison of
  - Elastic scattering on a free nucleon and
  - Quasi-elastic scattering from a bound nucleon
  - Especially interested in the electric form factor of the proton

Elastic Scattering of Electrons

- Elastic cross section of eN scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{\text{Mott}} \left[\frac{Q^4}{q^4}(1+\tau)G_E^2 + \left(\frac{Q^2}{2q^2} + \tan^2\frac{\theta}{2} \right) (2\tau G_M^2) \right]$$

- Form Factors
  - G_E: Charge distribution
  - G_M: Magnetization distribution

Quasi-Elastic Scattering

- Almost elastic scattering on moving nucleons inside the nucleus

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{\text{Mott}} \left[\frac{Q^4}{q^4} R_L(q,\omega) + \frac{Q^2}{2q^2} \frac{1}{\varepsilon} R_T(q,\omega) \right]$$

$$\varepsilon = \left[1 + \frac{2q^2}{Q^2} \tan^2 \frac{\theta}{2} \right]^{-1}$$

- Roughly, R_L corresponds to G_E, R_T corresponds to G_M

Coulomb Sum

- Integral of R_L at constant q

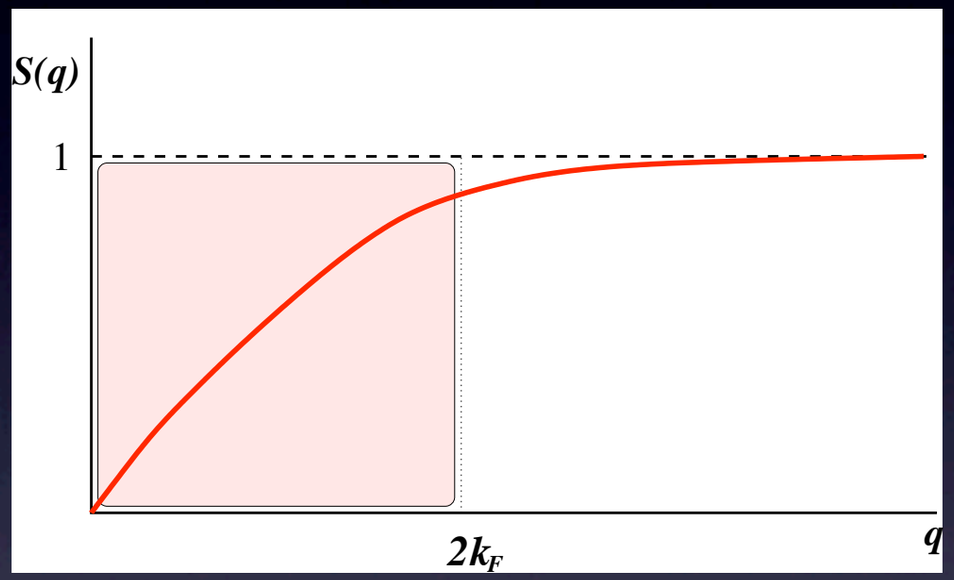
$$S_L(q) = \int_{\omega_{\rm el}^+}^{\infty} d\omega \frac{R_L(q,\omega)}{Z\tilde{G_E}^2(Q^2)}$$

- Denominator: contribution from electric form factors of protons and neutrons

$$\tilde{G_E}^2(Q^2) = \left([G_E^p(Q^2)]^2 + (N/Z)[G_E^n(Q^2)]^2\right)\frac{1+Q^2/4M^2}{1+Q^2/2M^2}$$

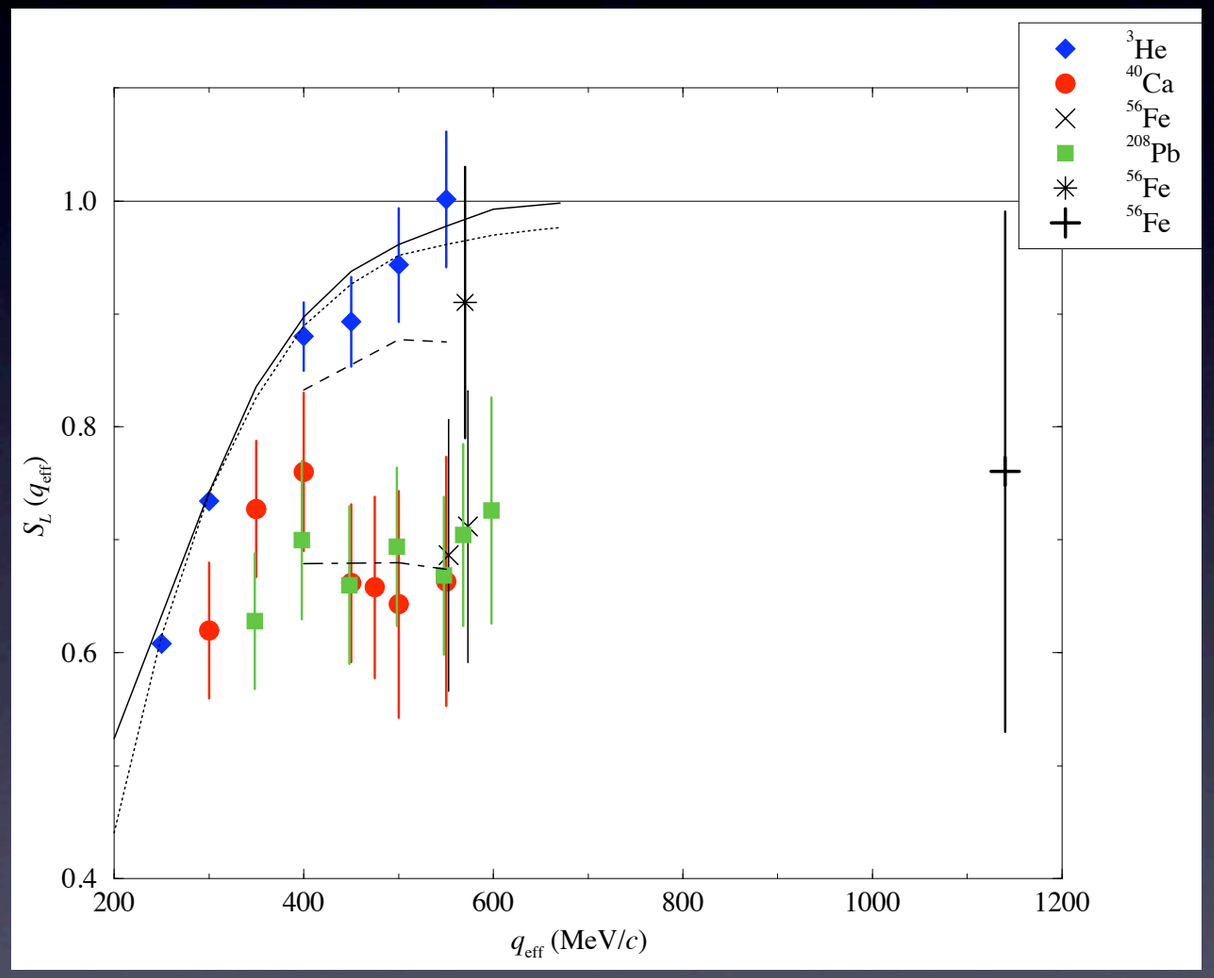
Saturation/Quenching of the Coulomb Sum

- Coulomb Sum Rule
  - $S_L(q) \to 1$ at sufficiently large q
- Deviation from the unity
  - at small q
    - Pauli blocking
    - NN long-range correlations
  - at large q $(\gg 2k_F)$
    - Short range correlations (small, ~ 10% at most)
    - Modification of nucleon properties in the nuclear medium



Previous Measurements

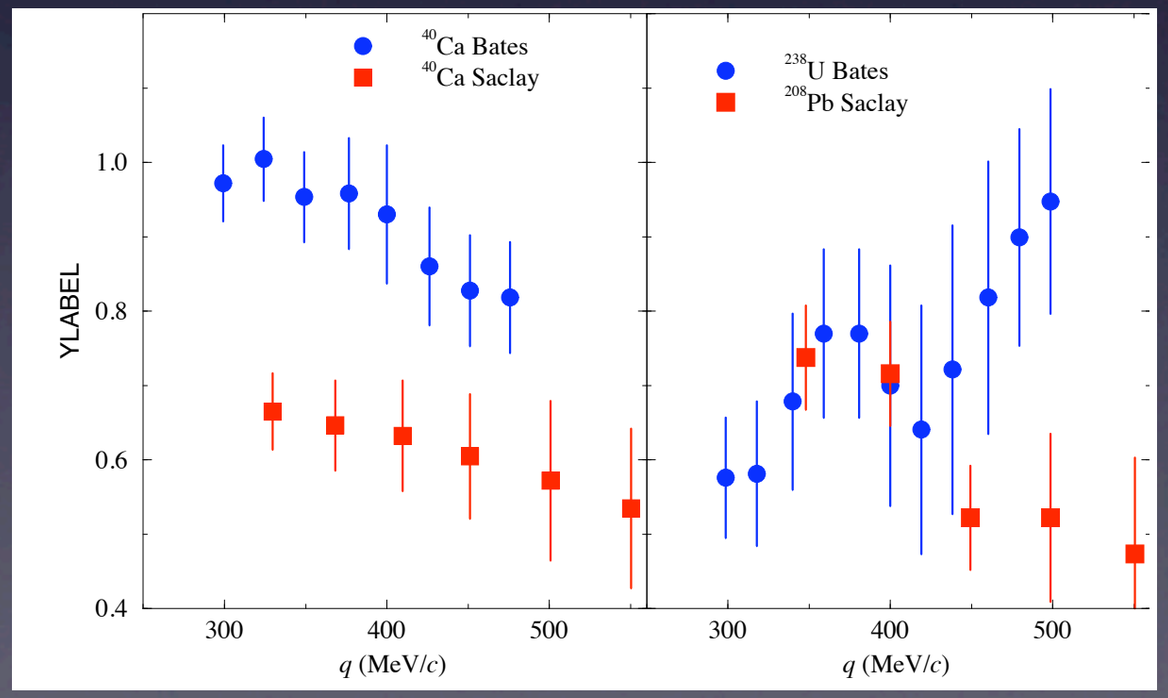
- For the past 20 years, a large experimental program at Bates, Saclay and SLAC
- Saturation of the Coulomb sum still controversial
- Limited kinematic coverage in q and ω



The figure does NOT include all the existing data.
Especially, MIT Bates results are not included

Controversy on CSR

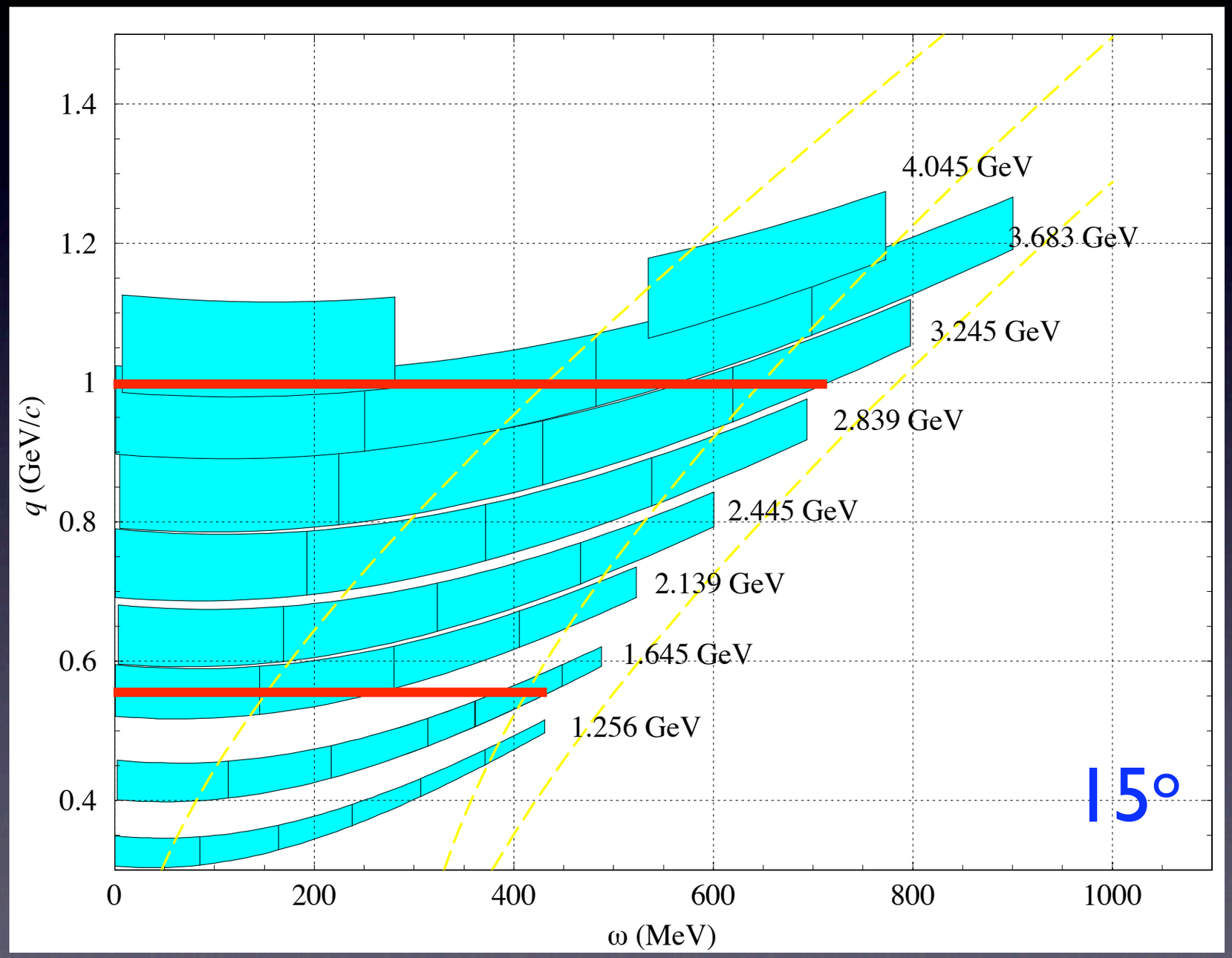
- Early data shows significant quenching.
- With the addition of forward angle data, Bates claims NO significant quenching.
- Saclay new analysis claims that quenching persists.



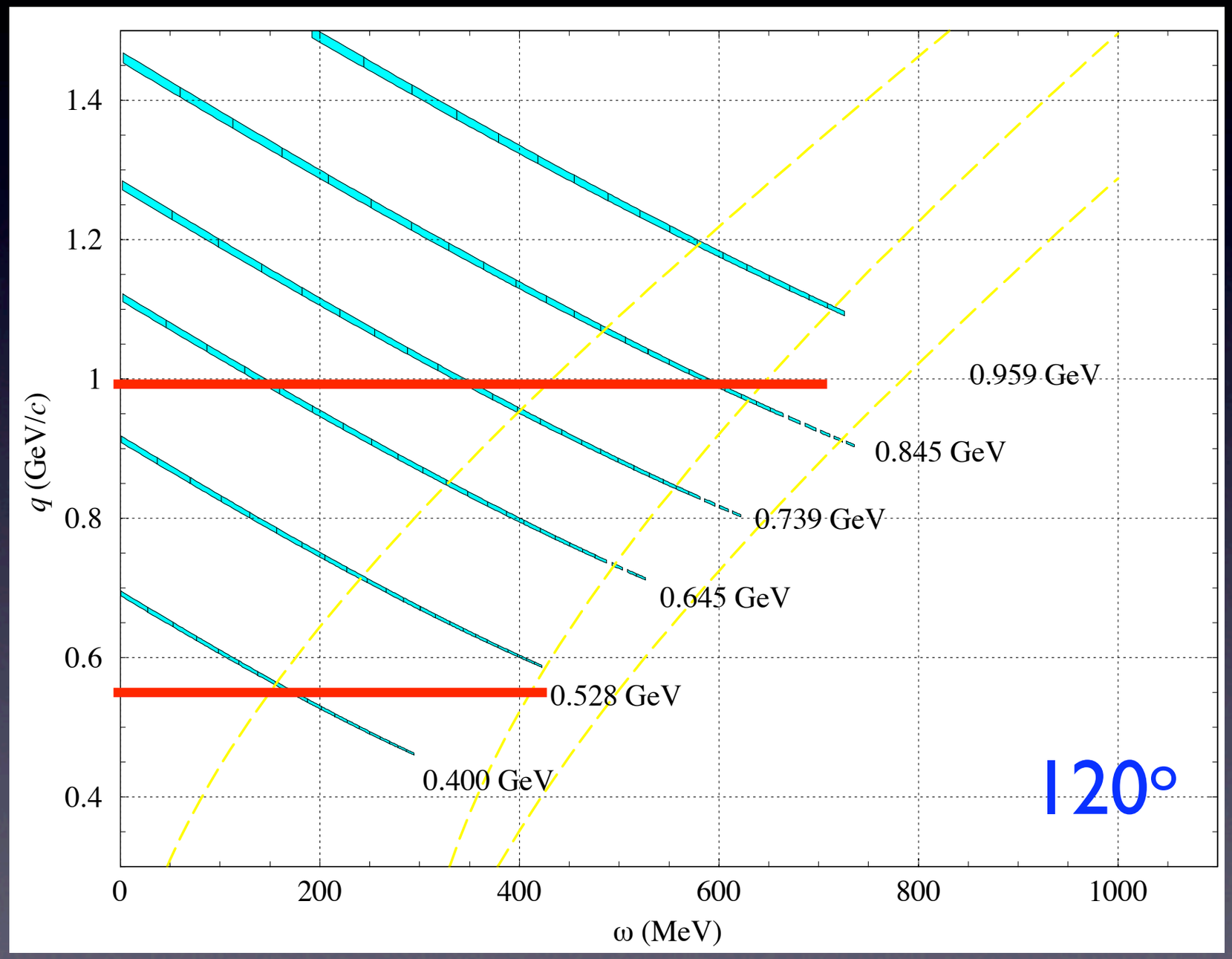
New Experiment at JLab

- Beam: 16 energies from 0.4 to 4.0 GeV
- Scattering angles: 15°, 60°, 90°, 120°
- Targets: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb
- Spectrometer momenta range from 4 GeV down to 100 MeV
- Covers q from 550 to 1000 MeV/c

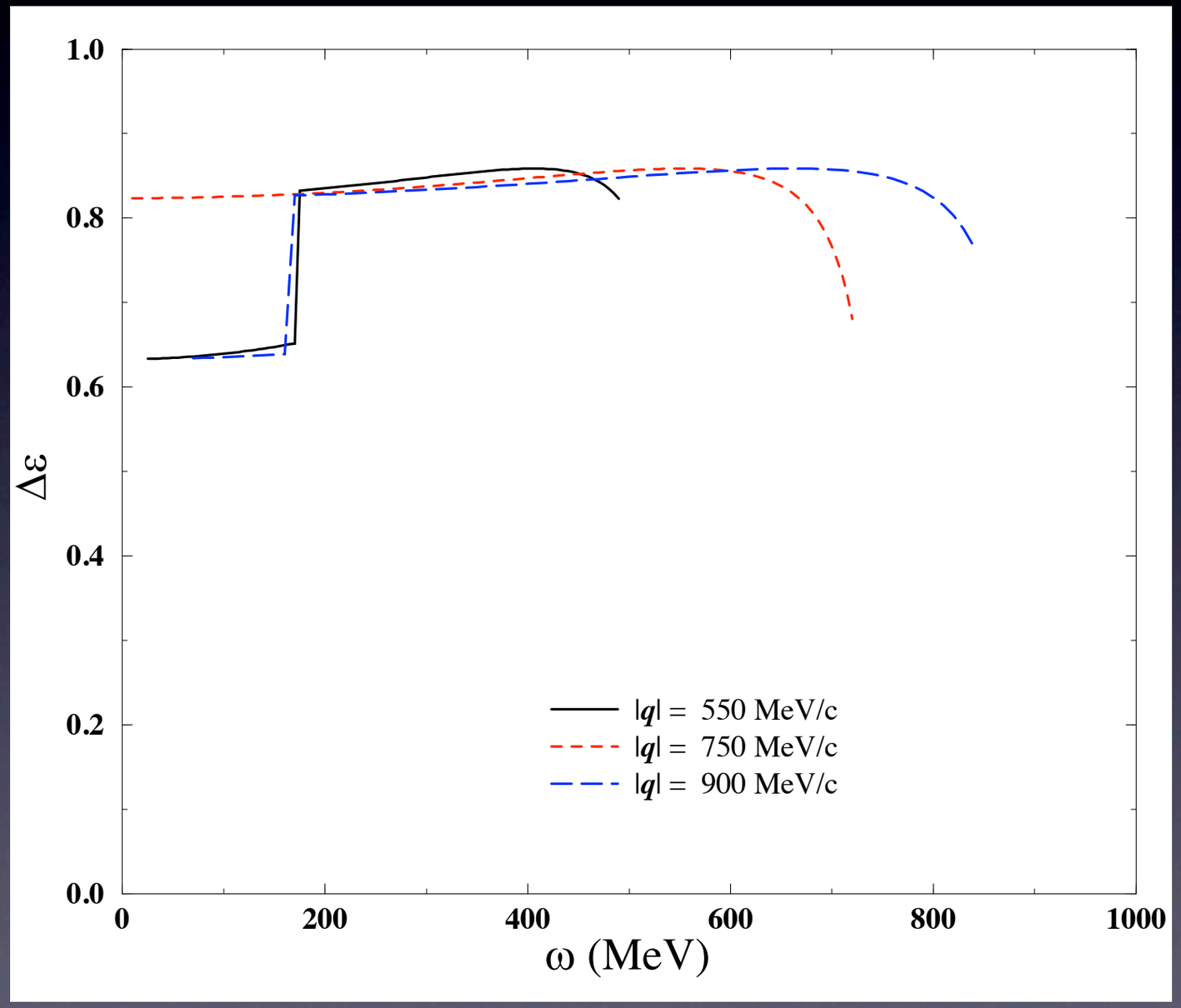
Coverage at 15°



Coverage at 120°



Lever Arm for Rosenbluth Separation

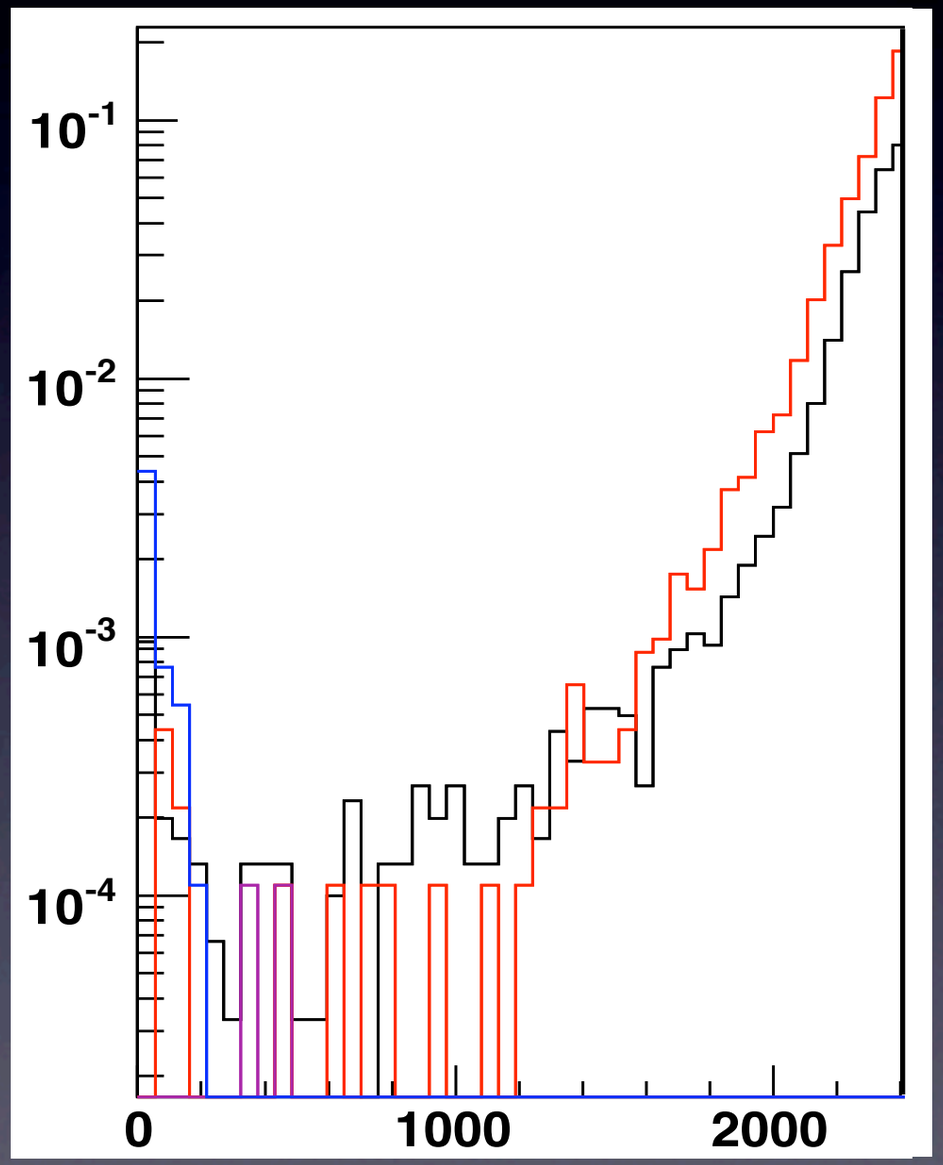


What's New?

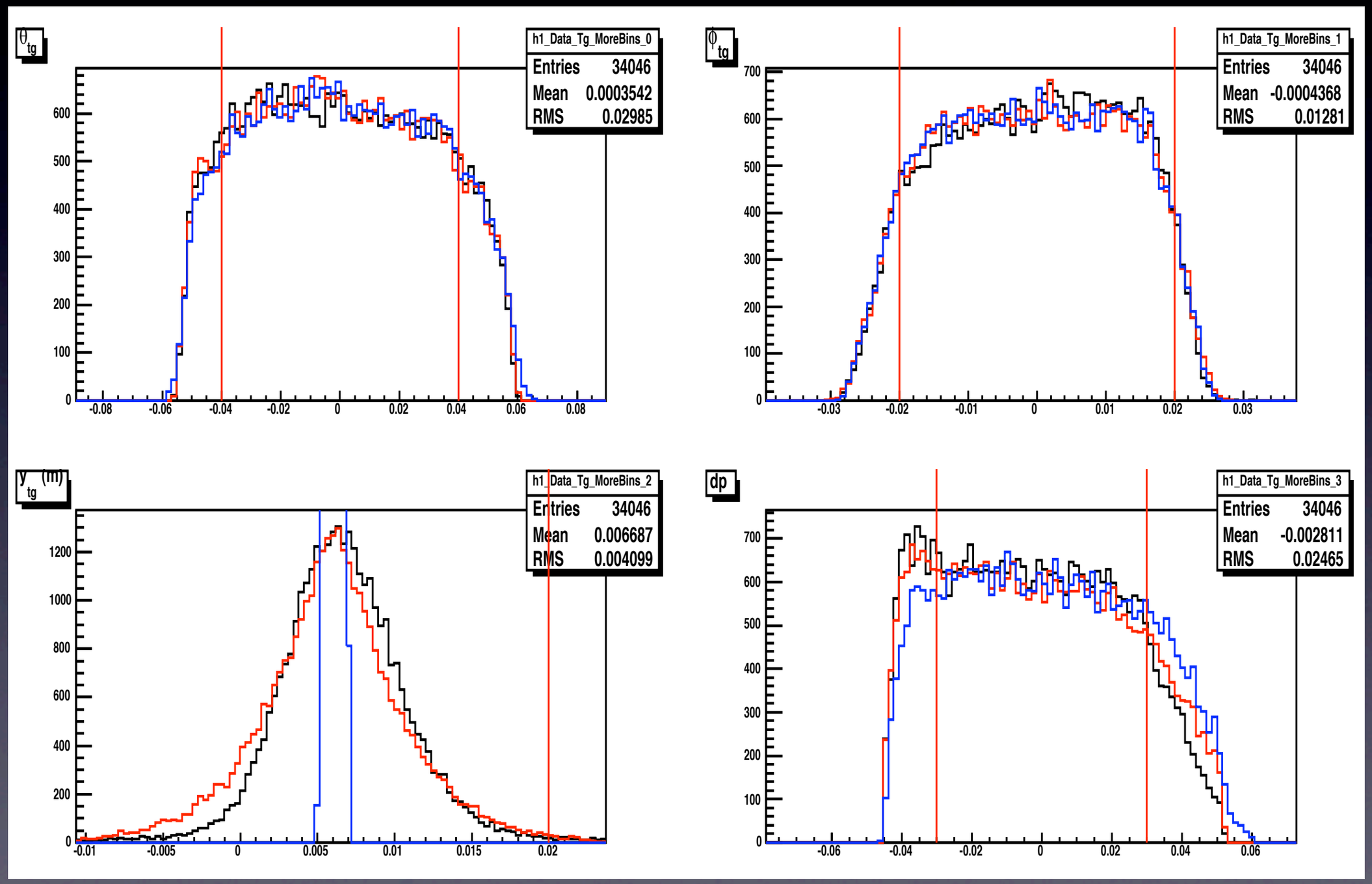
- Comfortable high values of q
  - From 550 MeV/c to 1000 MeV/c
  - High enough for clean observation of CSR
  - Previously unexplored region
- Comprehensive single experiment
  - Largest lever arm
  - Measurement at 4 angles
- Better control of background with NaI detector

Detector Performance

- NaI Detector
  - Independent measurement of the electron energy
  - Control of low energy scattered electrons
- Simulation
  - Electrons reflected inside the spectrometer
  - Comparison of low energy tail



Acceptance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RMS 0.02985
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RMS 0.01281
ytg (m)
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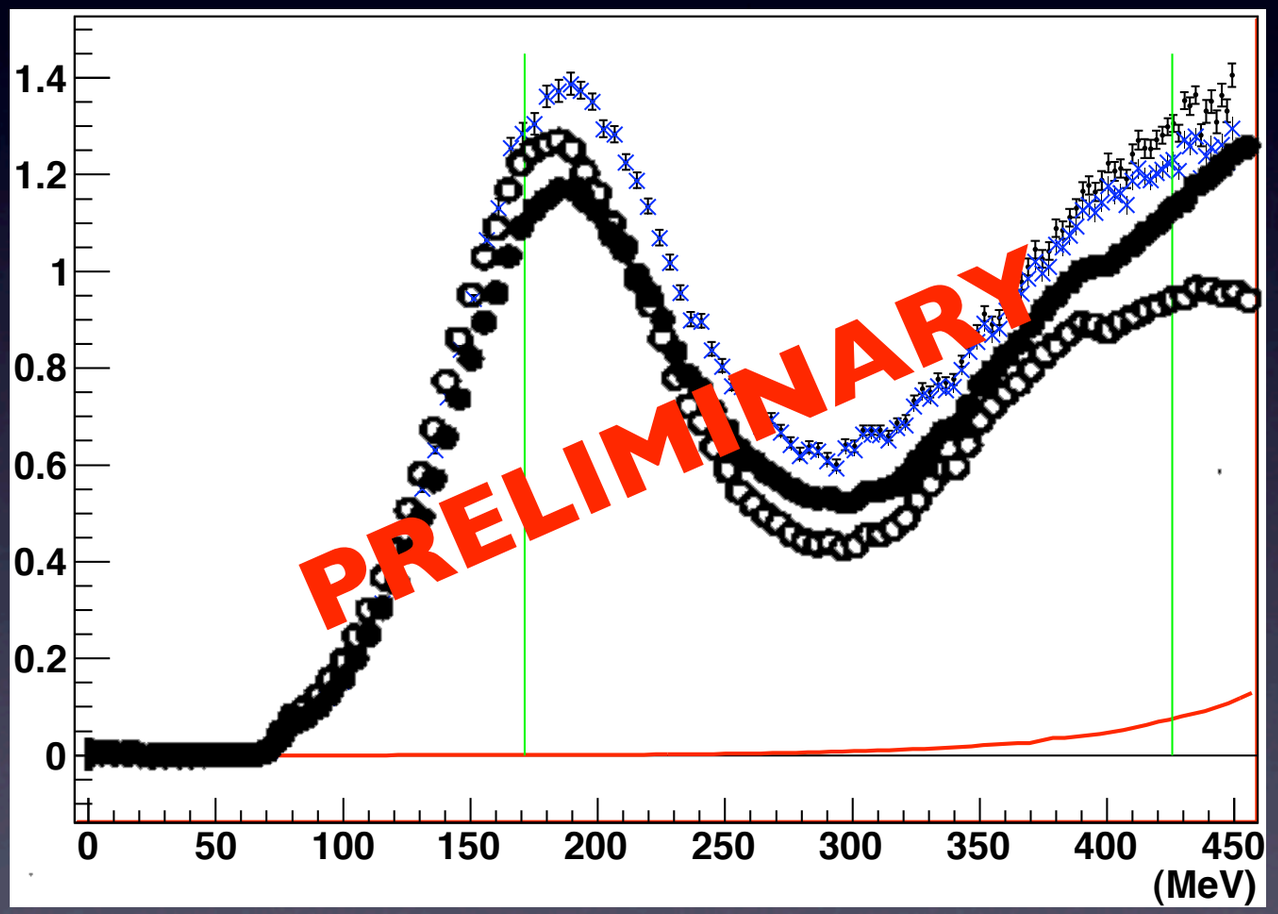
Entries 34046
Mean 0.006687
RMS 0.004099
dp
h1_Data_Tg_MoreBins_3
Entries 34046
Mean -0.002811
RMS 0.02465

Preliminary Cross Section Comparison

- ^{4}He target
- JLab: 646 MeV, 60°
  - Blue cross: No radiative corrections yet
- Saclay: 640 MeV, 60°
  - Filled circle: without radiative corrections
  - Open circle: after the radiative corrections



Summary

- Precision measurement of RL and RT over QE scattering range
  - Momentum transfer: 550 MeV/c to 1000 MeV/c
  - On four nuclei: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb
- Experiment completed successfully
  - A few new features compared to previous measurements
- Analysis in the final stage
  - Preliminary cross sections obtained
  - Radiative corrections in progress
- Hope to resolve the controversy on the Coulomb Sum Rule

Expected Error